Changing Fire Regimes, Increased Fuel Loads, and Invasive Species: Effects on Sagebrush Steppe and Pinyon-Juniper Ecosystems

Final Report

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The Influence of Environmental Attributes on Temporal and Structural Dynamics of Western Juniper Woodland Development and Associated Fuel Loading Characteristics

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Progress

All field measurements were completed in 2001 and 2002. Data have been entered, analyzed, and preliminary results have been generated. Data interpretation and compilation are nearly complete and both a thesis and publication are in progress.

Introduction

Since European American settlement western juniper (*Juniperus occidentalis* spp. *occidentalis* Vasek) has rapidly expanded beyond its pre-settlement range and has significantly increased in density. Concerns related to these changes in community composition are increased soil erosion, changes in soil fertility, losses in forage production, changes in wildlife habitat, and alterations of pre-settlement plant communities. Other concerns are related to changes in fire behavior as an artifact of excessive fuel loading in late successional woodlands. Despite the innate heterogeneity of landscapes occupied by juniper woodlands in various phases of development, juniper woodlands are often treated generically in land management.

Justification

Considerable work has been done documenting woodland expansion across the Intermountain West. However, little is known about the environmental variables that determine the rate of expansion and development and structure of woodlands across landscapes. Most studies on western juniper have addressed site-specific questions at limited spatial scales. Consequently, there is a lack of research on broader scale patterns of woodland development occurring across heterogeneous landscapes.
In addition, changes in the amount, composition, and structure of fuels during the transition from open sagebrush steppe communities to closed juniper woodlands have profound influences on the size, intensity, frequency, and behavior of fire. However, limited data exist quantifying changes in fuels during this transition, thus, consequences to fire behavior have been difficult to predict.

Study Objectives

The major objective of the study was to describe the influence of environmental variables on woodland development and associated fuel loading during the transition from sagebrush steppe communities to closed juniper woodlands.

Specific study objectives were to:

1. Describe the spatial and temporal attributes of woodland expansion into mountain big sagebrush communities across southeastern Oregon and southwestern Idaho.

2. Determine the influence of environmental variables (e.g. elevation, aspect, etc) on the temporal attributes of post settlement western juniper encroachment (both initial and successive tree establishment) into mountain big sagebrush communities in southeastern Oregon and southwestern Idaho.

3. Determine the influence of environmental variables on western juniper woodland structure (e.g. stand density) in stands encroaching into mountain big sagebrush communities in southeastern Oregon and southwestern Idaho.

4. Describe changes in the amount and structure of fuel loads associated with woodland development under varying environmental conditions in juniper stands encroaching into mountain big sagebrush communities on Juniper Mountain, Idaho.

Experimental Protocol

In 2001, 340 juniper stands were sampled in 0.5 ha plots along four transects ranging from 15 to 20 km in southwestern Idaho (Juniper and South Mountains) and southeastern Oregon (North and South Steens Mountain). Phase of woodland development (i.e. early = I, intermediate = II, or late = III) was identified for each stand following criteria developed by Miller et al. (2000). These three phases can be described as:

- Phase I, trees are present but shrubs and herbs are the dominant vegetation that influence ecological processes on the site;
- Phase II, trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes on the site;
- Phase III, trees are the dominant vegetation and the primary plant layer influencing ecological processes on the site.

Tree density was measured by counting each tree rooted within the plot and the three tallest trees were aged to estimate initiation of woodland expansion. Environmental variables (e.g. slope, aspect, elevation, etc.) were recorded for each stand and regression models were fit to predict total juniper density, dominant juniper density, and woodland development rate on stand elevation and site exposure. An index of site exposure based on slope and aspect was employed to estimate direct incident radiation that a site experiences. The equation first rescales aspect in degrees east of north to a scale of -1 to 1, with -1 being the coolest slope (north) and 1 being the warmest slope (south), and then relativizes by steepness of slope.

In 2002, thirty stands were revisited in southwestern Idaho to sample stand chronologies and fuels more intensively. Ten trees from four size classes were cored (n = 990). Ring widths on core samples were measured, relativized by the overall mean ring width, and resulting relative growth rates were plotted graphically to estimate years elapsed since establishment until stand closure. A regression model was fit to predict years transpired since stand establishment until stand closure on stand elevation and site exposure. Basal circumference above the root crown was measured on all trees rooted in three 6 x 60 m belt transects to estimate tree component biomass (Gholz 1980). The average depth and diameter of the litter mat under each aged tree was recorded and biomass estimates for duff were generated (Brown et al. 1982). The number of intersections by downed dead woody material were tallied by diameter class (one, ten, hundred and thousand hour

fuels) along a 60 m transect and biomass was estimated (Brown 1974). Shrubs and grasses were measured within five regularly located belt transects (2 x 12 m) partitioned into 6, 1 m^2 microplots. Elliptical crown diameter and maximum height measurements were obtained on mountain big sagebrush to estimate crown area, percent cover, and shrub biomass (Rittenhouse and Sneva 1977). Perennial grasses and perennial forbs were measured and clipped in twenty 1 m^2 microplots to determine basal area, percent cover, and biomass. One-way analyses of covariance (ANCOVA) were conducted to determine the effect of PHASE (i.e. I = early development, II = intermediate development, and III = late development) controlling for stand elevation and site exposure on the following eight fuel loading variables: tree biomass/ha, shrub biomass/ha, herbaceous (fine) biomass/ha, duff biomass/ha, one hour fuel biomass/ha, ten hour fuel biomass/ha, hundred hour fuel biomass/ha, and thousand hour fuel biomass/ha.

Preliminary Results

Spatial and Temporal Attributes of Woodland Expansion

Western juniper occurred in 95% of the stands sampled across the study area (n=340). An average across the study locations indicates that nearly a third of the sampled stands were classified in each of the three phases of development employed in this study with about five percent being comprised of predominantly pre-settlement age class trees (Figure 1). The fact that only about a third of woodlands are in the late phase of development suggests the majority of the study area is still in a state of vegetation transition.

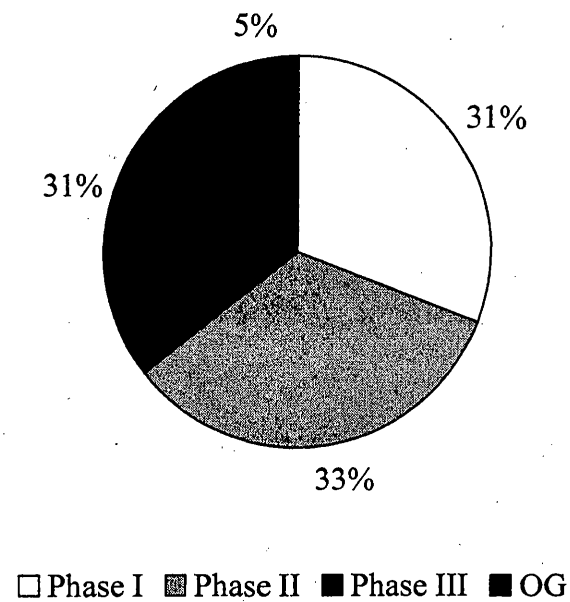

Figure 1. Average proportion of stand development across the study areas. Phase I = trees present but shrubs and grasses dominate the site, Phase II = trees codominant the site with shrubs and grasses, Phase III = trees dominate the site and shrubs and grasses have declined, and OG = stands with >25% of the trees older than 150 years.

The Idaho area (Juniper and South Mountains) had a higher proportion of old growth woodlands (i.e. stands in which the dominant overstory was comprised of pre-settlement

age class trees) than the Oregon study locations (North and South Steens Mountain) (Figure 2). In addition, the proportion of Idaho stands supporting pre-settlement trees (i.e. presence of at least one pre-settlement age class tree) was also higher than the Oregon study locations (Figure 3), 58% and 23% respectively. However, although the Idaho study locations had a higher proportion of stands supporting old growth than Oregon, pre-settlement trees averaged 10 percent or less of total tree density for all locations (Figure 4). The fact that pre-settlement trees occurred in 48% and 67% of sampled stands on Juniper and South Mountains, respectively, but comprised less than ten percent of total tree density suggests a scattering of pre-settlement trees across the study area. Pre-settlement age tree density averaged about 13 trees/ha and current tree density averaged 322 trees/ha, representing about a 25-fold increase in juniper density.

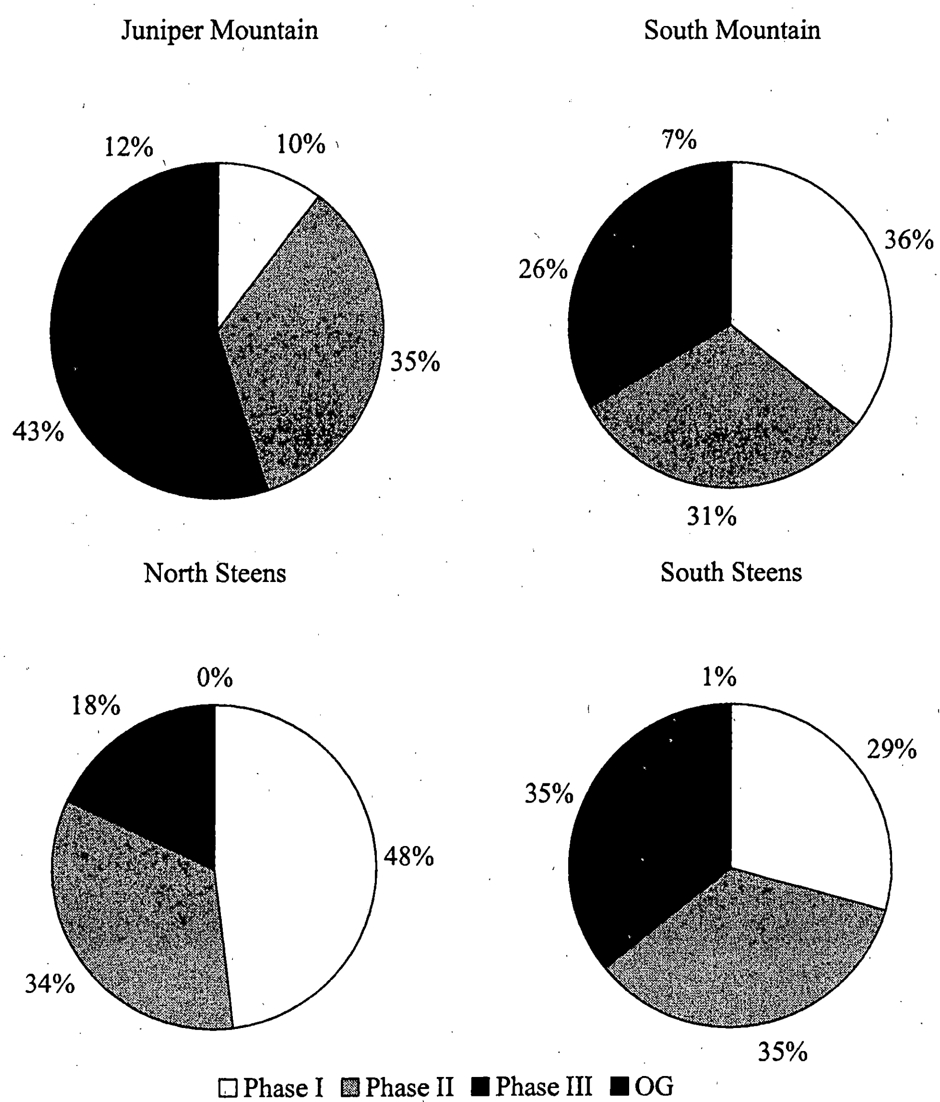

Figure 2. Proportion of stand development for each study location. Phase I = trees present but shrubs and grasses dominate the site, Phase II = trees codominant the site

with shrubs and grasses, Phase III = trees dominate the site and shrubs and grasses have declined, and OG = stands with >25% of the trees older than 150 years.

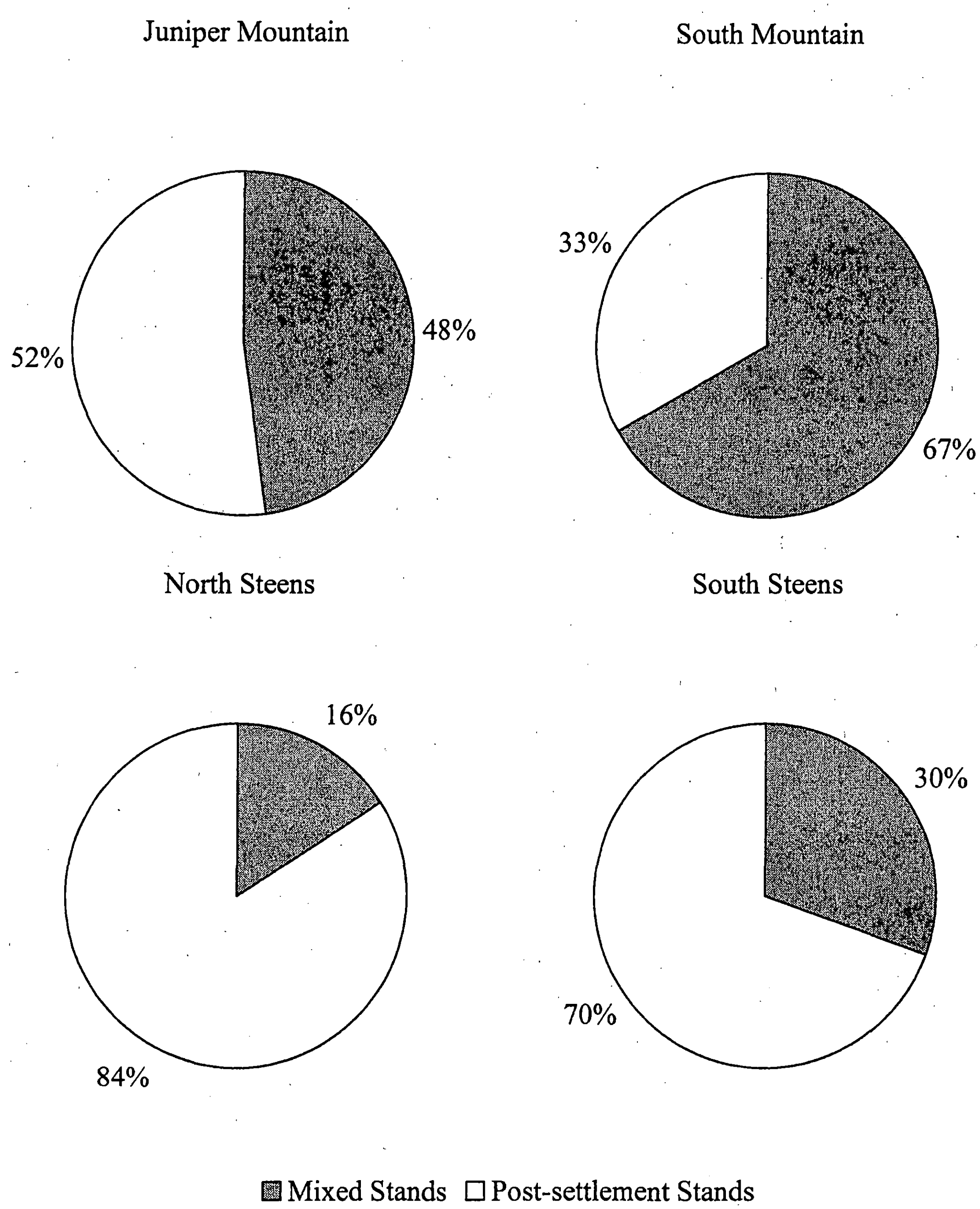

Figure 3. The proportion of mixed age and post settlement age stands for each study location. Mixed age stands supported at least one pre-settlement age class tree, but pre-settlement trees did not necessarily make-up the dominant overstory. Note that a higher proportion of the Idaho study locations (i.e. Juniper and South Mountains) supported pre-settlement trees than the Oregon sites (i.e. North and South Steens Mountain).

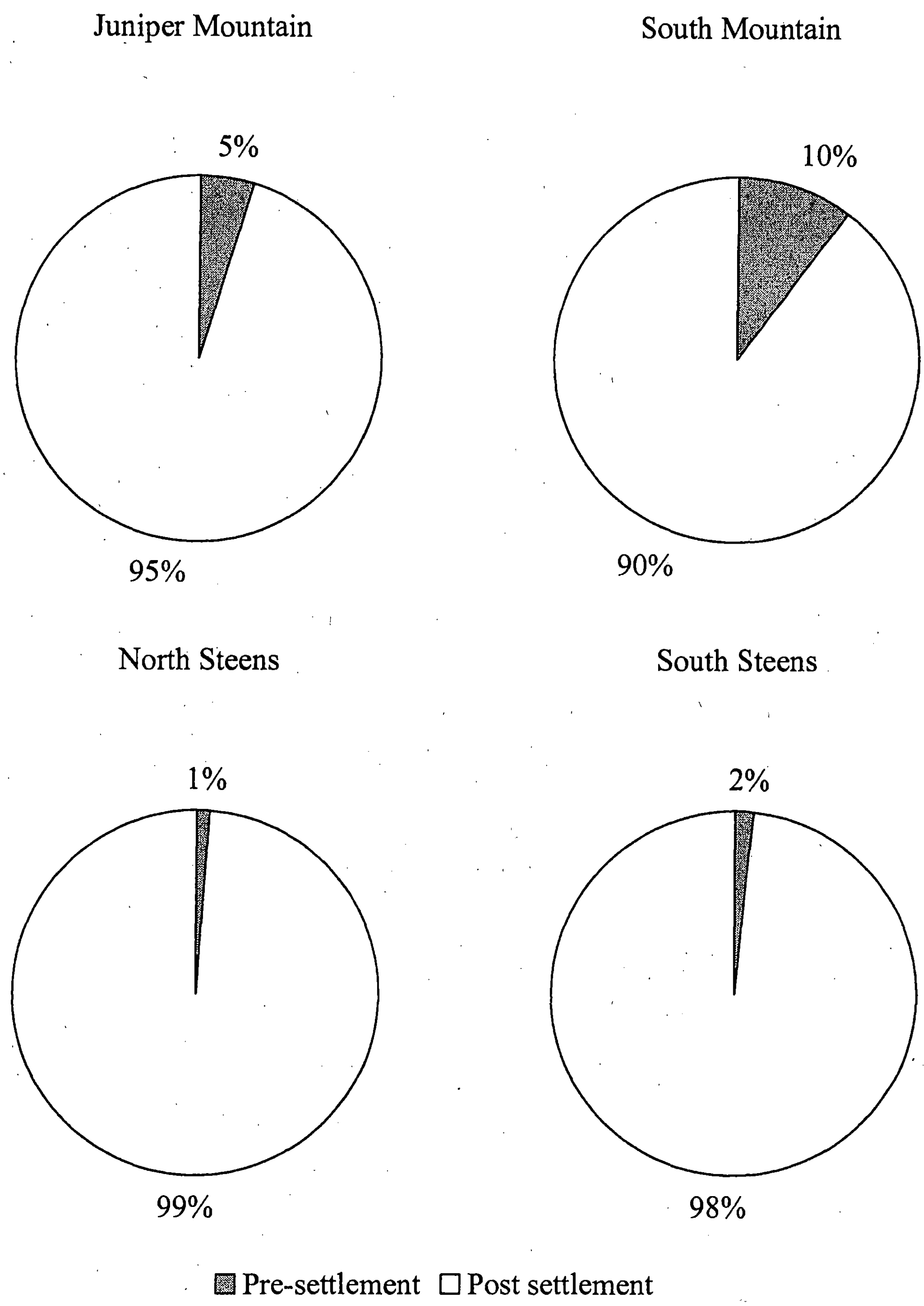

Figure 4. The proportion of pre-settlement age class trees for each of the study locations. Pre-settlement trees were greater than 150 years old. Note that although the Idaho study locations (i.e. Juniper and South Mountains) had a higher proportion of pre-settlement

trees than the Oregon sites (i.e. North and South Steens Mountain), these trees combined for 10% or less of total tree density.

The presence of pre-settlement trees in a greater proportion of the Idaho stands likely led to earlier initiation and more rapid rate of woodland expansion (Figure 5) due to proximity to seed source. Tree establishment in thirty percent of the sampled stands in Idaho occurred prior to 1880 whereas only two percent of sampled stands in Oregon established during this time period. Greater than 98% of initial tree establishment occurred after 1870 on sites in Oregon with a peak occurring from the 1890s through the turn of the 20th century. Conversely, greater than 50% of initial establishment corresponding to the Idaho sites occurred prior to the turn of the century.

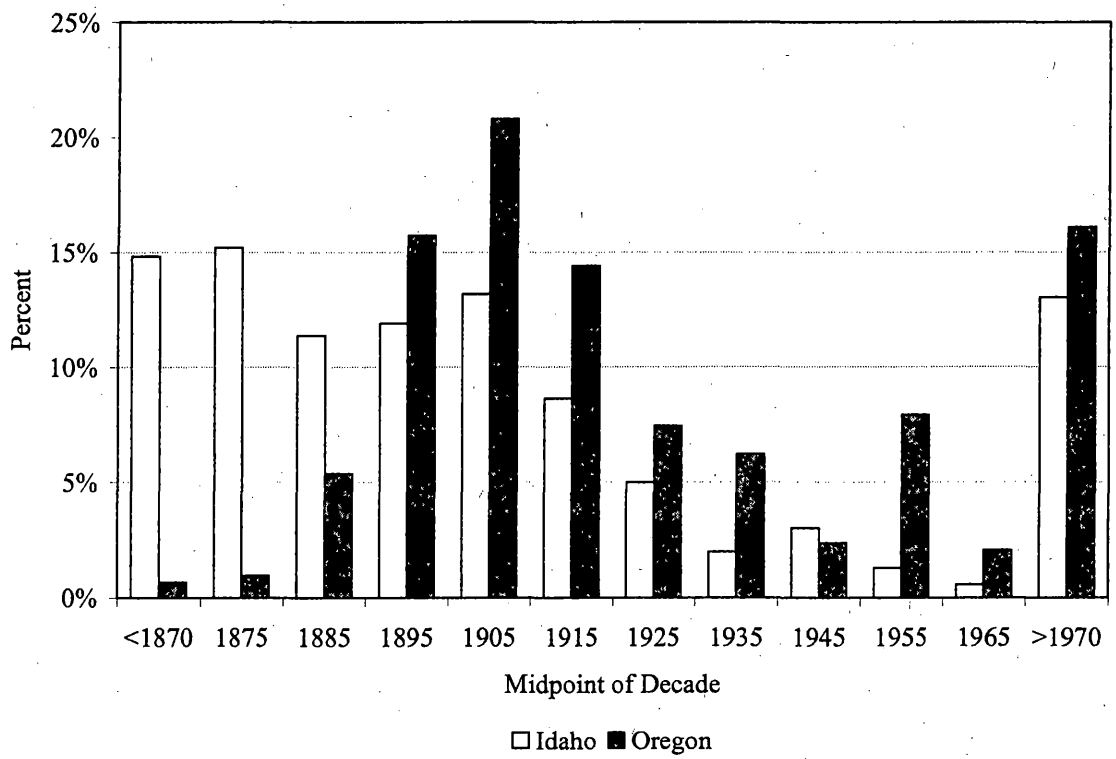

Figure 5. Combined decadal frequency of stand initiation for Idaho and Oregon study areas. Each column denotes the proportion of sampled stands that established during the corresponding time period. The final columns represent phase I stands or stands that lacked trees. Note the periods of earlier tree establishment for the Idaho study area.

Influence of Environmental Variables on Rate of Woodland Development

The relationship of rate of woodland establishment with site exposure and elevation is summarized in Figure 6. The regression model describing this relationship was (standard errors in parentheses):

$$\text{Rate of Establishment} = \underset{(4.73)}{-10.41} - \underset{(0.028)}{0.25} * \text{site exposure} + \underset{(0.0026)}{0.009} * \text{stand elevation}$$

with residual error = 2.4. The adjusted r^2 was 0.6.

The rate of woodland development (#trees established/ha/year) decreased with increasing southerly exposure and increased with increasing elevation. A 20-unit increase in site exposure (e.g. contrast of stands developing on similar hillslopes and elevation but facing south instead of north) is associated with a 4.9 trees/ha/year decrease in the rate of woodland establishment (95% CI: 3.8 to 6.03 trees/ha/year). A 200 m rise in elevation is associated with a 1.84 trees/ha/year increase in the rate of woodland establishment among stands with similar exposure (95% CI: 0.8 to 2.88 trees/ha/year).

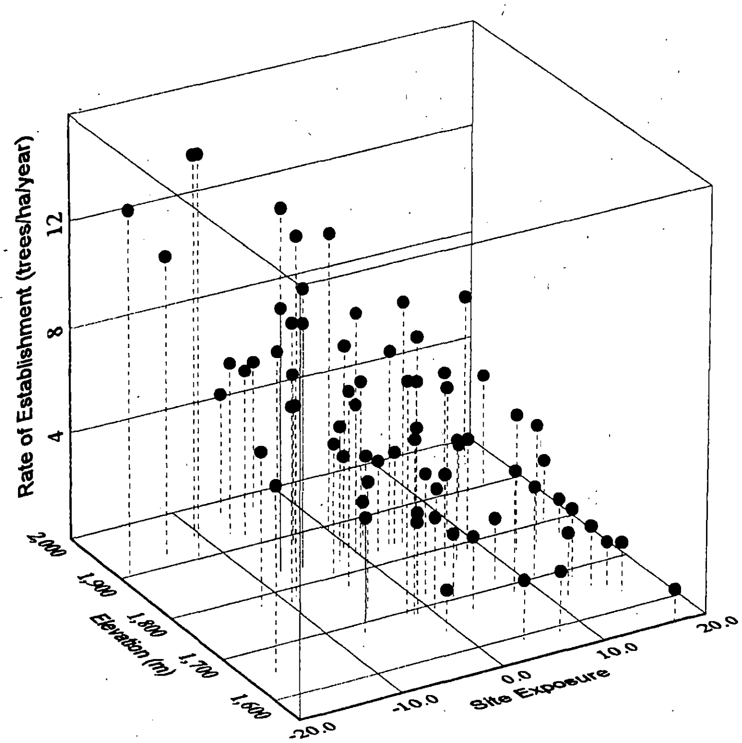

Figure 6. Relationship of rate of establishment with elevation (m) and site exposure. Site exposure is an index based on aspect and slope calculated as follows: site exposure = slope * cosine(π * (aspect – 180)/180). Site exposure becomes increasingly warmer to the right.

The relationship of the number of years required to reach stand closure with site exposure and elevation is displayed in Figure 7. The regression model describing this relationship was (standard errors in parentheses):

$$\text{Years Until Stand Closure} = \underset{(45.58)}{193.66} + \underset{(0.117)}{0.48} * \text{site exposure} - \underset{(0.025)}{0.052} * \text{stand elevation}$$

with residual error = 4.29. The adjusted r^2 was 0.73.

The number of years required to reach stand closure increased with increasing southerly exposure and decreased with increasing elevation. A one unit increase in site exposure (i.e. increasing southerly exposure) is associated with a 0.48 year increase in the time required to reach closure among stands that have developed at similar elevations (95% CI: 0.22 to 0.74 year). A 100 m rise in elevation is associated with a 5-year decrease in the time required for a stand to reach closure on sites with similar exposure (95% CI: 0.37 to 10.81 years).

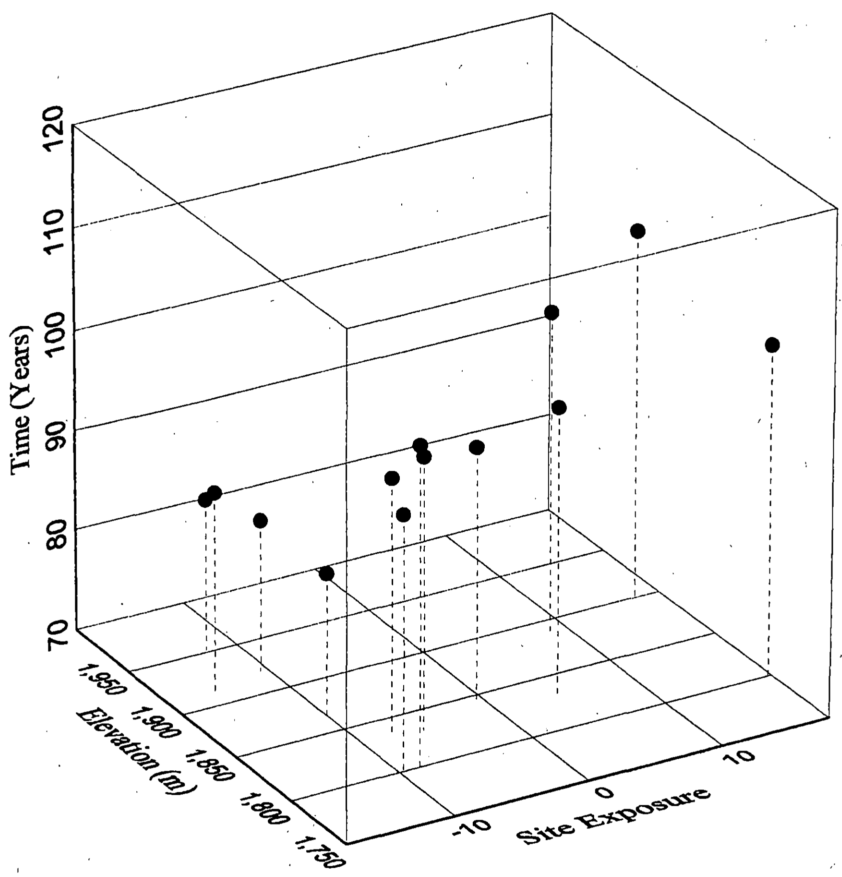

Figure 7. Relationship of time required to reach stand closure with elevation (m) and site exposure. Site exposure is an index based on aspect and slope calculated as follows: site exposure = slope * cosine(π * (aspect – 180)/180). Site exposure becomes increasingly warmer to the right.

Influence of Environmental Variables on Woodland Structure

The relationship of total live juniper density with elevation and site exposure is shown in Figure 8. The final regression model describing this relationship was as follows with standard errors in parentheses below the estimates (response variable log transformed to meet model assumptions):

$$\text{Log(Total Tree Density)} = \underset{(0.705)}{2.59} - \underset{(0.004)}{0.036} * \text{site exposure} + \underset{(0.0004)}{0.0022} * \text{stand elevation}$$

with residual error = 0.356. The adjusted r^2 was 0.65.

Total live tree density decreased with increasing southerly exposure and increased with elevation. A 5-unit increase in site exposure (e.g. contrast of stands on similar hillslopes and elevation but facing south instead of east) is associated with an 18% decrease in total tree density (95% CI: 14 to 22%). A 100 m rise in elevation is associated with a 22% increase in total tree density among stands with similar site exposure (95% CI: 14 to 30%).

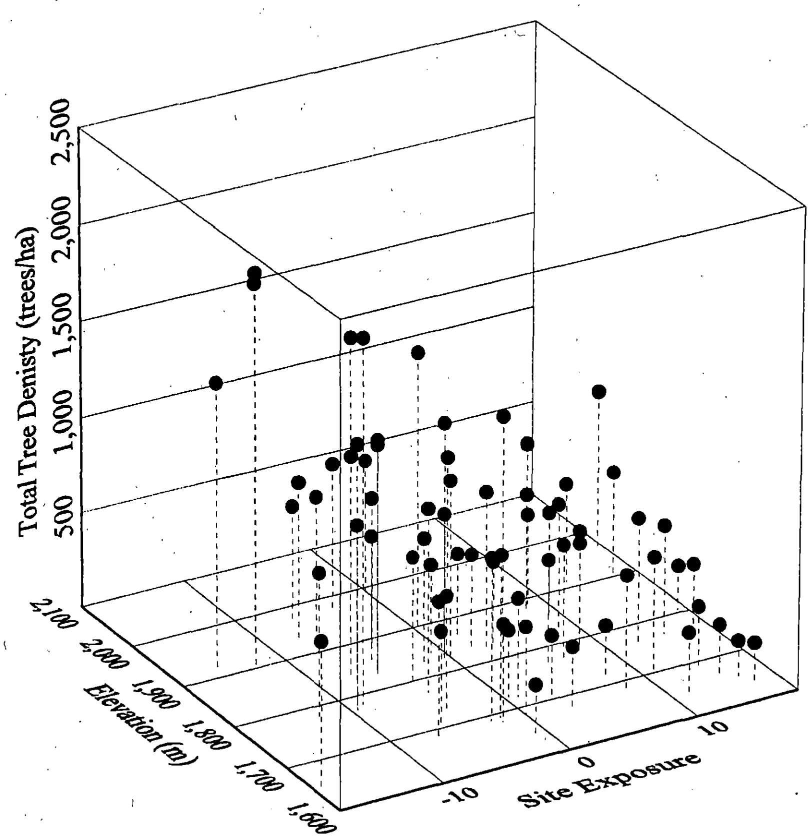

Figure 8. Relationship of total live juniper density with elevation (m) and site exposure. Site exposure is an index based on aspect and slope calculated as follows: site exposure = slope * cosine(π * (aspect – 180)/180). Site exposure becomes increasingly warmer to the right.

The relationship of dominant juniper density (number of trees/ha comprising the upper 75% of the canopy) with elevation and site exposure is shown in Figure 9. The final regression model describing this relationship was as follows with standard errors in parentheses below the estimates (response variable log transformed to meet model assumptions):

$$\text{Log(Dominant Tree Density)} = \underset{(0.836)}{2.62} - \underset{(0.005)}{0.026} * \text{site exposure} + \underset{(0.0001)}{0.001} * \text{stand elevation}$$

with residual error = 0.36. The adjusted r^2 was 0.49.

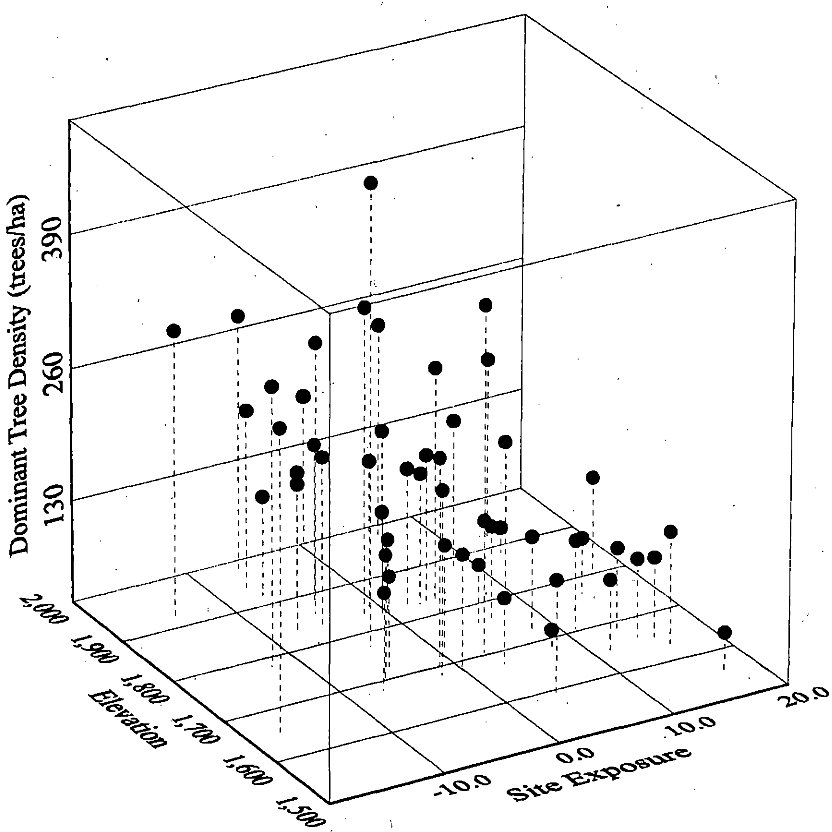

Figure 9. Relationship of dominant juniper density with elevation (m) and site exposure. Site exposure is an index based on aspect and slope calculated as follows: site exposure = slope * cosine(π * (aspect – 180)/180). Site exposure becomes increasingly warmer to the right.

Dominant tree density decreased with increasing southerly exposure and increased with elevation. A 5-unit increase in site exposure (e.g. contrast of stands on similar hillslopes and elevation but facing south instead of east) is associated with an 15.4% decrease in total tree density (95% CI: 9.6 to 21%). A 100 m rise in elevation is associated with a 22% increase in total tree density among stands with similar site exposure (95% CI: 8 to 11%).

Changes in Fuels During Woodland Development

There were significant differences across the three phases of woodland development in herbaceous, shrub, tree, duff, one hour, and thousand hour fuel biomass ($p < 0.05$). Contrasts of phase I estimates with phase II and III estimates are summarized in Table 1. Herbaceous and shrub biomass has declined markedly during the transition from open shrub steppe communities to closed woodlands. It's estimated that median herbaceous biomass has declined 59% during this transition (95% C.I.: 45 to 70%), while median shrub biomass has declined 95% (95% C.I.: 92 to 97%), among stands at a similar elevation and with similar exposure. Median tree biomass is estimated to have increase by 54.1 fold during the transition from open to closed juniper woodland communities (95% C.I.: 37 to 79 fold). Mean shrub and herbaceous biomass mass was about 5,300 and 1,900 kg/ha in open mountain big sagebrush communities and about 235 and 700 kg/ha in closed woodland stands. The measured shrub and herbaceous species averaged 96% of the total live fuels biomass in shrub steppe dominated communities, whereas this combination averaged less than 2% of the total live fuel biomass in late phase juniper stands, indicating a dramatic shift in the composition of live fuel loading.

Table 1. Estimates of change in fuels biomass during transitions from phase I to phases II and III of woodland development. 95 % confidence intervals for estimates are also presented.

	Phase I → Phase II[a]			Phase I → Phase III[b]		
Response	**Estimate (%)**	**95% C.I. (%)**		**Estimate (%)**	**95% C.I. (%)**	
Herbaceous	84[c]	56	125	41	30	55*
Shrub	25	22	32*	5	3	8*
Tree	480	294	798*	5410	3700	7900*
Duff	405	329	490*	431	374	500*
One hour	115	64	204	166	108	257*
Ten hour	82	44	155	127	79	205
Hundred hour	50	9.7	255	39	12	134
Thousand hour	806	155	4200*	965	108	8626*

[a] Estimated changes in biomass from phase I to phase II
[b] Estimated changes in biomass from phase I to phase III
[c] Interpret as median herbaceous biomass in phase II is 84% of what it was in phase I.
* 95% C.I.s that exclude 100% (i.e. no change in median biomass).

Conclusions

Data suggest that rate of woodland expansion and density of trees increased with elevation and northerly exposure. The lightly shaded area in Figure 10 shows the estimated time period necessary for stands developing under varying environmental conditions to yield a minimum stocking of trees and reach full dominance by juniper. Stands on mesic sites achieved a minimum stocking of over 250 trees/ha in less than 25 years, whereas 40 to 50+ years were required to achieve a minimum stocking of fewer than 100 mature trees/ha on drier sites. Relative growth rates in closed woodlands indicate intraspecific competition between juniper trees began in the late 1950s and early 1960s. We speculate that this was a period of canopy closure and rapid decline in understory vegetation, especially shrubs. The intermediately shaded area in Figure 10 represents the time period from stand establishment to stand closure given a site's environmental variables. It was found that drier sites support fewer total trees in a closed state than mesic sites, <340 trees/ha as opposed to >900 trees/ha, respectively. Stand closure occurred within 120 to 170 years on warm dry sites compared to 80 to 120 years on cool moist sites

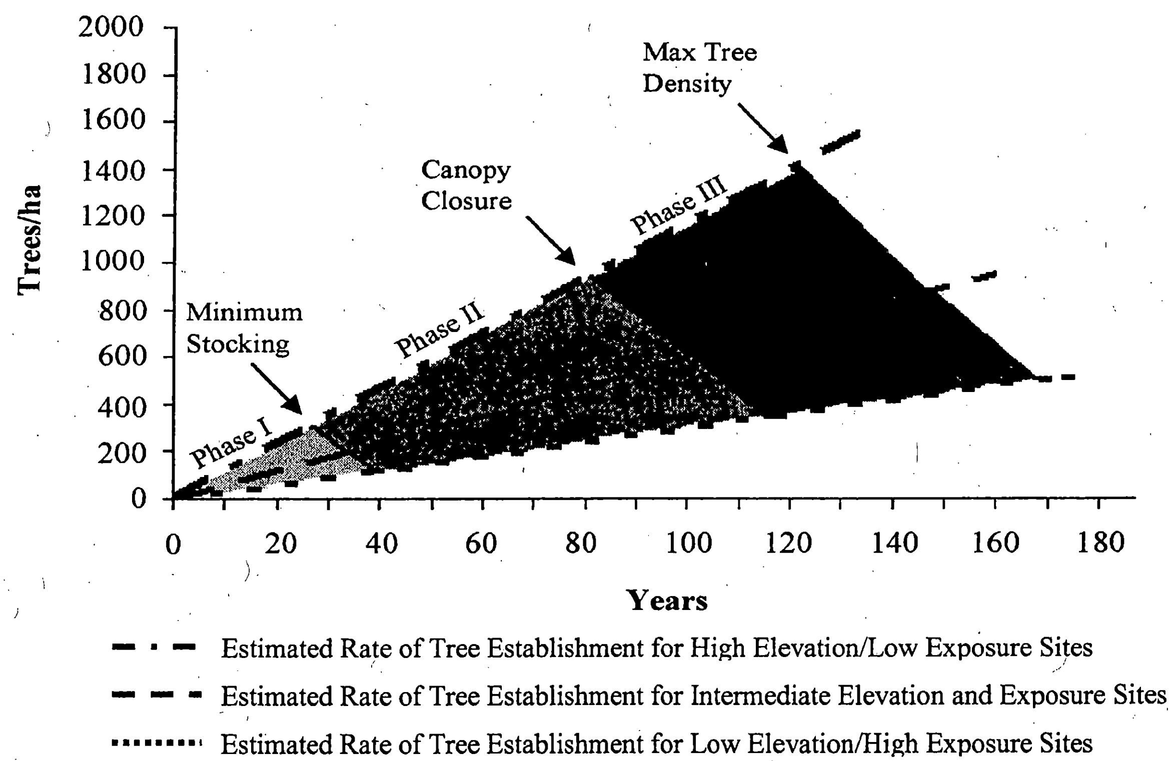

Figure 10. Display showing the hypothesized time periods required from initial tree establishment to minimum stocking, stand closure, and estimated maximum tree density for stands developing under varying environmental conditions.

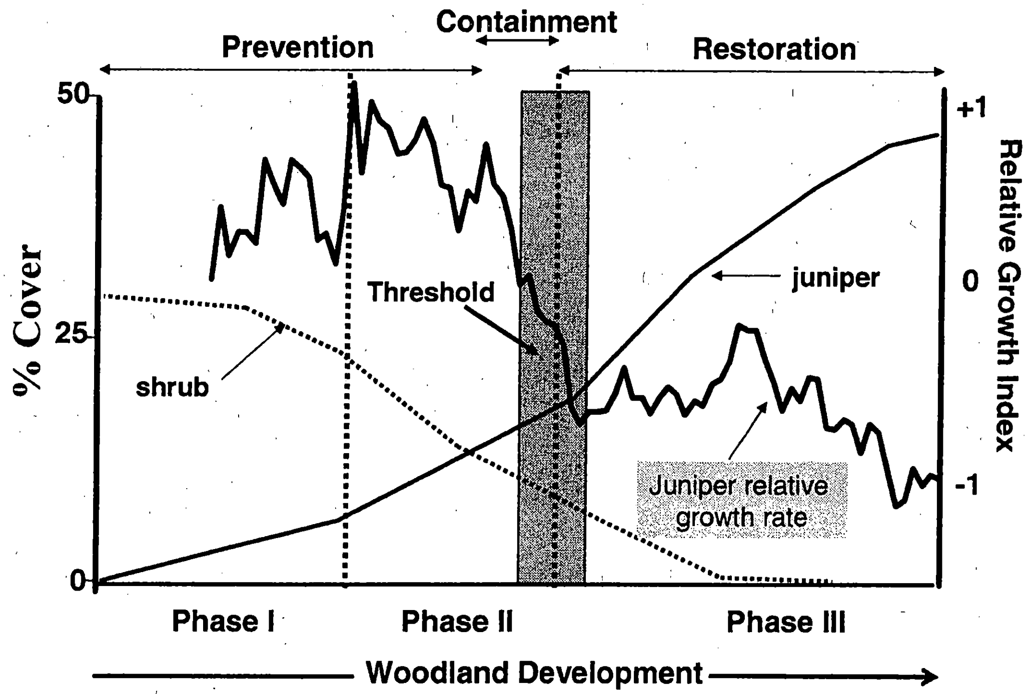

Figure 11. Relationship between shrub canopy cover, tree canopy cover and relative growth rates (i.e. ratio of annual ring width over mean ring width), and management intensity during different phases of woodland development.

As woodlands develop community structure significantly changes impacting fire regimes, fire behavior, restoration options and costs, forage production and wildlife habitat. The threshold shown in Figure 11 represents a point where intra-specific competition among trees begins and the understory rapidly declines. The above example represents a closed woodland that initiated expansion in the 1860s and relative growth rate rapidly decline in the late 1950s. The decline in fine and ladder fuels significantly changes the fire regime from a ground fire to canopy fire. Prescribe fire is only feasible with mechanical treatment greatly increasing the cost of management. Although the potential for fire in Phase III is less than in Phases I and II, fire intensity and severity are much greater in Phase III. Intervention of woodland expansion is best done during Phase I and during the early portion of Phase II.

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